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Overview of Past, Present and Future Marine Power Plants

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Abstract: In efforts to overcome an foreseeable energy crisis predicated on limited oil and gas supplies, reserves; economic variations facing the world, and of course the environmental side effects of fossil fuels, an urgent need for energy sources that provide sustainable, safe and economic supplies for the world is imperative. The current fossil fuel energy system must be improved to ensure a better and cleaner transportation future for the world. Despite the fact that the marine transportation sector consumes only 5% of global petroleum production; it is responsible for 15% of the world NO_x and SO_x emissions. These figures must be the engine that powers the scientific research worldwide to develop new solutions for a very old energy problem. In this paper, the most effective types of marine power plants were discussed. The history of the development of each type was presented first and the technical aspects were discussed second. Also, the fuel cells as a new type of power plants used in marine sector were briefed to give a complete overview of the past, present and future of the marine power plants development. Based on the increased worldwide concerns regarding harmful emissions, many researchers have introduced solutions to this problem, including the adoption of new cleaner fuels. This paper was guided using the same trend and by implementing the hydrogen as fuel for marine internal combustion engine, gas turbines, and fuel cells.
Keywords: marine power plants; alternative fuels; gas turbines; diesel engines; hydrogen engines; fuel cells; hydrogen fuel

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1 Introduction

The introduction of fossil fuels started out slowly as a replacement of coal for all transportation sectors, dating back from the beginning of the 20th century. But, not until the early the 70's of this century did the world start to realize the danger of interrupting fuel supplies. This interruption was due to the oil crisis during the Arab-Israeli war in 1973 and the Islamic revolution in Iran in 1979. The western developed countries started to think about energy independence and later they were convinced by the environmental drawbacks following the use of fossil petroleum products. Another issue had a considerable interest, the limited resources of petroleum products and the fact that every day the available quantity of oil is reduced; Fig. 1 shows the global energy supply from different sources as estimated to 2050.

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The world then started investigations and researches for non-petroleum fuels to be less harmful to the environment and reduce the dependency on foreign energy imports.

Biofuels are considered as one of the suggestions; they are not new since Rudolph Diesel's work was based on the use of vegetable oil as fuel for his invention (Knothe, 2001). But the problem of emissions of greenhouse gases still exists, with this type of method, because carbon is one of the main constituents. In other words the biofuels are one type of hydrocarbons and do not solve the problem totally.

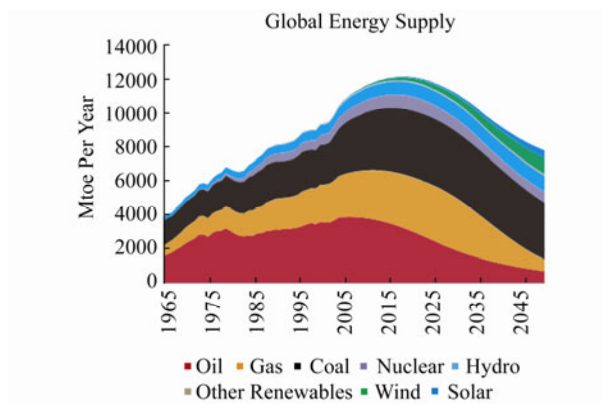

Fig. 1 Global energy supply projection to 2055

1.1 Natural gas as a fuel

Another suggestion was natural gas, like the biofuels, it has less emission levels than petroleum products but the problem of limited resources remains. But the fact that the natural gas is fossil, i.e. it is ready to be used without the need for further scientific developments, this fact makes the natural gas the ideal temporary solution to replace the other petroleum fuels because the biofuels pass in a long chain to reach the final consumer, some links in this chain require additional researches.

The use of natural gas in internal combustion engines has been researched thoroughly to reach the optimum case in both engine performance and environmental impact. Both types of internal combustion engines were studied; the compression ignition and the spark ignition engines. All problems associated with the use of natural gas in these engines were dependent of the injection timing inside the engine cylinders and the cylinder geometry, accurate control is needed to avoid engine knocking and high emission formation levels. Lean burn concepts also were investigated to reach low emission

conditions (Zhang and Frankel, 1998; Zeng *et al*., 2006; Papagiannakis and Hountalas, 2004).

Another application for the natural gas, is the gas turbines field; it is used worldwide in electric generation stations either alone or in cogeneration plants where the resulting heat is used for district heating purposes to increase the plant overall efficiency. In Egypt 58% of the country's gas production goes to the electric generation sector, accounting for nearly 75% of the total generating capacity (US DOE, 2008). Almost all gas turbine manufacturers produce units working with natural gas, and in fact, gas turbines are better used with gas rather than liquid fuels. This method is a better choice for the cleanliness of gas combustion and the elimination of the soot production that deposit on the turbine blades. From the emissions viewpoint the natural gas itself produces less emissions in gas turbines than in internal combustion engines, except for CO2 because of the higher fuel consumption in gas turbines and its lower efficiency than internal combustion engines (Canova *et al*., 2008).

1.2 Hydrogen as a fuel

Another resource thought to be the fuel of the future for decades is hydrogen gas. The scientific research concerning the use of hydrogen in transportation began shortly after the first oil crisis. Many car manufacturers started development programs to produce cars that could operate by hydrogen fuel in internal combustion engines (DeLuchi, 1989). The beginning was in Germany and Japan and the USA followed them. Nowadays, the USA has national programs for the development of hydrogen systems especially for fuel cell applications to overcome any combustion related problems (US DOE, 2007).

Combustion of hydrogen inside internal combustion engines has been, and still is, the subject for many research programs in many countries. Like the natural gas, the main problems associated with the application of hydrogen in internal combustion engines include the engine knocking; air fuel ratio and intake temperature were found to be the main causes for this problem and their optimization is a must to have a knock free engine (Hailin and Ghazi, 2004)

Some problems were discovered to be only related to the hydrogen due to its special characteristics; these characteristics are the high flame speed and the low ignition energy, the problems associated are the steep rise of cylinder pressure and possibility of fuel pre-ignition leading to potential explosions inside the engine systems (Banawan *et al*., 2010; Ma *et al*., 2003).

Regarding the emissions, it is evident that the hydrogen produces fewer emissions almost in all engine operating conditions, due to the higher combustion temperature in hydrogen engines, the NOx rates were found high in some cases and many solutions were produced, all of them use well proved technologies used nowadays with normal engines, these technologies include exhaust gas recirculation and catalytic reduction filters (Heffel, 2003; Ho *et al*., 2008).

Most of the researches done on hydrogen internal combustion engines have as result a slight increase in the engine thermal efficiency with a decrease in engine output power and torque (White *et al*., 2005).

For the application of hydrogen in gas turbines, the scientific community witnessed many research programs and technical investigations to study the characteristics of hydrogen combustion inside gas turbine combustors. Basically there are three methods applied in the gas turbine market to reduce emissions from ordinary gas turbines powered by petroleum products or natural gas; dry low NOx combustors, flame dilution by the addition of steam or adding catalytic reducers at the exhaust systems. Not all of these techniques can be used with hydrogen due to its special combustion characteristics (Chiesa *et al*., 2005).

All researches have common conclusions; the direct substitution of natural gas or other fuel oils results in an increase in NOx levels and the reduction of these levels necessitates additional modification to be made to the combustor design in the dry combustor designs or increasing the rate of dilution achieved by steam addition (Ziemann *et al*., 1998; Dahl and Suttrop, 1998).

In order to achieve the maximum benefits from using the hydrogen, many ideas encouraged the use of blends of natural gas with hydrogen with different proportions either in internal combustion engines or gas turbines, the results for engines showed the improvement of the natural gas case when the emissions are considered, but for the gas turbines, the admission of hydrogen to natural gas in ordinary combustors without special measures to reduce NOx resulted in increased emission rates (El-Gohary, 2012).

Another use of hydrogen is the fuel cells. Huge developments have been achieved in this sector over the past few years. But for the marine field only the naval vessels market used it for auxiliary power generation and quiet operation of submarines, and for commercial market the development achieved so far is not enough to convince ship owners to use this fine technology product. From all types of fuel cells, only two are the candidates for the use onboard; the proton exchange membrane fuel cell (PEMFC) and the molten carbonate fuel cell (MCFC) fueled by hydrogen rich fuels like natural gas or alcohols (Alkaner and Zhou, 2006; Tomczak *et al*., 2002).

2 Overview of marine power plants

The International Maritime Organization amended its 1973 MARPOL convention by Annex VI for the air pollution from ships; this annex limited the maximum emission rates from ships. Following these new regulations engine manufacturers started to develop new methods and techniques to reduce the SO_x, NO_x and CO_2 emissions from their engines to meet the new limits.

One key solution for the emission problems from marine engines was to achieve fuel consumption savings by introducing more accurate engine control techniques resulted in the birth of electronically controlled engines. Also, common rail fuel systems were one of the results of the

extensive researches made to achieve low fuel consumptions and lower emissions rates. Other techniques like selective catalytic reduction and water injection inside the diesel engine cylinders were also adopted (Woud and Stapersma, 2003).

In 2006, 1642 commercial ships of more than 2000 GT were built worldwide with 1617 of them powered by 1917 diesel engines, these engines' power capacity was in the order of 22000 MW (Woodyard, 2004). In spite of the fact that more than 98% of the commercial vessels were powered by diesel engines, more ships are constructed every year with gas turbine units for electric generation purposes especially in the passenger transportation sector.

Before reviewing the main types used nowadays of marine power plants, the power plant itself must be defined first.

The marine power plant is that part of the ship responsible for generating both mechanical and electrical power for the ship propulsion and various electric consumers. Usually, these two operations are achieved separately, but in some configurations both are performed together. Fig. 2 shows diagrammatic representations for the two power plant options.

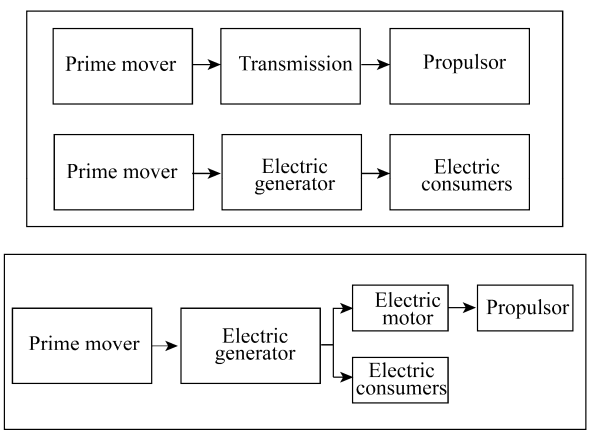

Fig. 2 Power plants options, (up) separate propulsion and electric generation (down) combined propulsion and electric generation

According to the above classification, the power plant may be of the electric type, where propulsion is done via electric motors, or the conventional type, where mechanical power from the prime mover drives the propulsion either directly or through a gearbox.

2.1 Types of traditional marine power plants

The marine power plants are mainly classified according to the type of the prime mover responsible for the propulsion power generation. Three main prime movers exist; internal combustion engines, gas turbines and steam turbines. Nuclear powered or oil fired boiler powered steam cycles are used with steam turbines according to the vessel type. Combinations of the previous types also exist and new technologies are gaining more and more concern worldwide, e.g. all electric ships.

The scope of this thesis focuses mainly on the commercial power plants, i.e. diesel engines, gas turbines and ordinary boiler steam cycles. Nuclear and electric power plants are out of scope since they are used in a small percentage of vessels worldwide and their advantages are favored in only a small sector of maritime transportation. Fuel cells as a new technology introduced recently to the marine sector will be highlighted in brief.

2.1.1 Steam power plants

The first application ever of steam power was in England in 1712 when Thomas Newcomen invented the first steam engine to pump water out of mines (see Fig. 3) (Harrington, 1992). In 1776 James Watt made basic improvements to the engine and his name is more frequently associated with steam engines development (Shlyakhin, 2005).

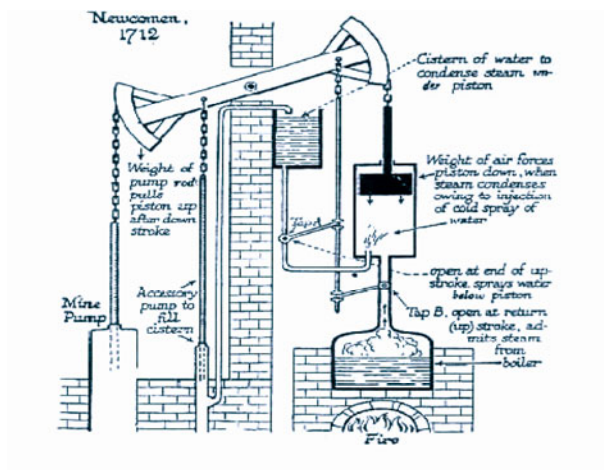

Fig. 3 Newcomen first steam engine

The application of steam engines in the marine field started in the 1780s in Europe and America simultaneously with at least seven steamers built until 1807 all of them working with Scotch (fire tube) boilers (Harrington, 1992).

Due to its increased efficiency and higher power to weight ratio if compared with the steam engine, the steam turbine has completely replaced the reciprocating steam engine. The first idea of steam turbine was established by Hero of Alexandria in 120 B.C. (see Fig. 4). Later in 1551, the Egyptian scientist Taqi El-Din developed an invention based on the steam turbine principle (Grove1839). In 1629, the Italian scientist Giovanni Branca described a machine based on the same idea (Grove, 1842). Finally in 1886, the known steam turbine was invented by Charles Parsons and few years later, the American George Westinghouse scaled up the output power, many variations and developments followed like the famous Curtis, de Laval and Rateau turbines.

Nowadays the major commercial user of steam power plants is the LNG (Liquefied Natural Gas) sector, where the BOG (Boil-Off Gas) from the natural gas cargo is burnt in boilers to generate steam (Lamb, 2004).

Fig. 4 Hero steam turbine

A typical steam power plant is composed of four main components; boiler(s), turbine(s), condenser and feeding pump. The boilers used in steam power plants are of the water tube type, where water flows inside the tube banks surrounded by hot combustion gases. Steam conditions at boiler exit are in the range of 40 bars and 250°C for saturated steam and 450°C for superheated steam, these values being lower than those achieved in land based steam plants limit the steam power plant efficiency to around 30% (Woud and Stapersma, 2003).

Auxiliary power onboard the ship is generated by means of steam turbo-generators but the presence of diesel gensets is unavoidable, either for peak load usage or as emergency generators. Also, some of the ship machinery may be steam driven like cargo pumps in case of large oil tankers (Lamb, 2004).

One of the key operations the main power plant has to achieve is the astern motion of the ship, in steam driven ships this is done by one of two methods; the first by using gearboxes able to reverse the motion in addition to speed reduction and in this method the steam turbine continues to run in the same direction, the second is by admitting the steam to separate astern stages within the low pressure turbine since the astern motion requires far less power than ahead motion.

The main manufacturers of marine steam turbines available on the market are Hyundai, Kawasaki and Mitsubishi with unit power ranging from 5 000 to 45 000 kW, while Siemens provide steam turbines with power up to 100 000 kW.

2.1.2 Diesel power plants

It was in 1824 when the French physicist Sadi Carnot established a new theory in heat engines stating the need for compression to increase the difference between the upper and lower working temperatures. Before Carnot, many internal combustion engines were invented but worked on a compression less principle giving very low power output and efficiency. After many trials and modifications, the German Nikolaus Otto working with Gottlieb Daimler and Wilhelm Maybach developed in 1876 the first four stroke engine working on the well known Otto cycle. After three years and based on the Otto work, Karl Benz developed the first two stroke engine in 1879. Few years later, the supercharging principle was patented after the work of Gottlieb Daimler in 1885.

The first compression ignition engine – the famous diesel engine – named after the German Rudolph Diesel received the first patent in 1893, but it was in 1900 that Diesel demonstrated his invention to the public in the Exposition Universally (International Fair) in France after the first successful operation in 1897. The major modification to the diesel engine was in 1902 when F. Rundolf invented the two stroke scavenged engine.

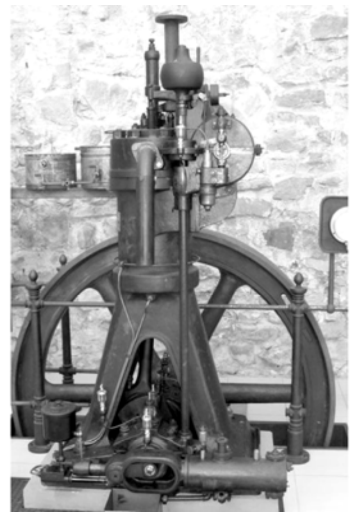

Fig. 5 One of the first diesel engines built by B&W in 1906

The first diesel engine propelled ship is believed to be the Russian river tanker Vandal built in 1903. Since then the diesel engines have been installed in many small units and by 1910 there were more than 30 commercial vessels over 30 m long in the world. In the same year 1910, the first seagoing vessel has been built, it was the Romagna fitted with Sulzer diesel engines delivering 280 kW at 250 r/min each.

Only two years after the introduction of the first motor ship, about 300 motor vessels have been in service with a total of 235 000 GRT (Gross Registered Tonnage). Ten years later there were about 2000 ships and that number grew to 8000 by 1940 constituting 60% of the world's tonnage at that time (Woud and Stapersma, 2003).

All diesel engines whatever their size or type works on the same air standard cycle, i.e. the Diesel cycle or the constant pressure air standard cycle. Diesel cycle engines are preferred over Otto cycle engines in marine field for the ability of the former to work with high pressure ratios, in Otto cycle knocking may occur at high compression ratios leading to reduced efficiencies and possible damage for the engine parts. This high pressure ratio allows the engine to develop more power for the same size.

Another aspect making the diesel engine preferred is its ability to work with low quality and thus low cost fuels which is an essential factor in a ship economics.

The distinction between the slow, medium and high speed ranges is not established officially but a range of 200 to 300 r/min is the margin between slow and medium speed while

between medium and high speed the range is from 1000 to 1200 rpm (Woud and Stapersma, 2003).

The diesel engines give good flexibility for the naval architect to achieve the required speed for a given ship with the best fuel economy. A ship propulsion system can be consisted of only one diesel engine and in some cases up to 12 engines - only for propulsion - especially in naval vessels requiring large propulsion flexibility and high redundancy levels like the world war II H-class German battleships (Zhang and Frankel, 1998). For the electric generation, the diesel engine is almost the only engine type used even with other types of prime movers used for propulsion. Also the diesel engines have the best efficiency levels of all other means of propulsion with a range of 35% to 55%.

2.1.3 Hydrogen internal combustion engine

The introduction of new fuel types like hydrogen into the field of maritime transport is considered to be a challenge due to the severe environmental conditions the marine power plant has to work in. Therefore, any attempt to introduce a new technology in this field must be accompanied by sufficient studies and experimental data to provide the engineers and ship operators with enough data about the new fuel type used. This data has to be experimentally approved but in the first and preliminary stages of design of power plants working with new fuels it may not be available or feasible to make large scale experiments, so a computer program is used to give reasonably accurate data about the new design. The demand on energy production will be increased by increasing the population and sea borne trade. The use of other alternatives oil should start to replace diesel oil onboard ships. Hydrogen is considered a good candidate for such replacement. This paper introduces the procedures followed to design a hydrogen internal combustion engine.

Many technologies are available these days or under research for hydrogen storage, but till now none of these have the ability to store as much hydrogen as the liquid storage methods. Hydrogen is suggested to be stored in insulated cryogenic tanks at −253˚C; the problem with this type of storage is its volume (4.15 times more than liquid hydrocarbon fuel for the same travel range (El-Gohary and El-Sherif, 2006).

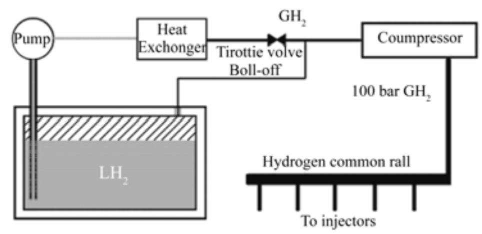

Fig. 6 Hydrogen fuel system

Hydrogen should be used as a marine fuel in internal combustion engines; this has been suggested to make use of the existing diesel engines used in order to prevent manufacturing new systems and minimize the cost to only modifications to existing engines. The suggested engine will operate on hydrogen directly injected into the cylinders. Low energy sparks will be needed to avoid using amounts of diesel fuel in order to initiate combustion. Fuel pumps and sparks are to be electronically controlled (cam less) to ensure the optimum performance at various operating conditions.

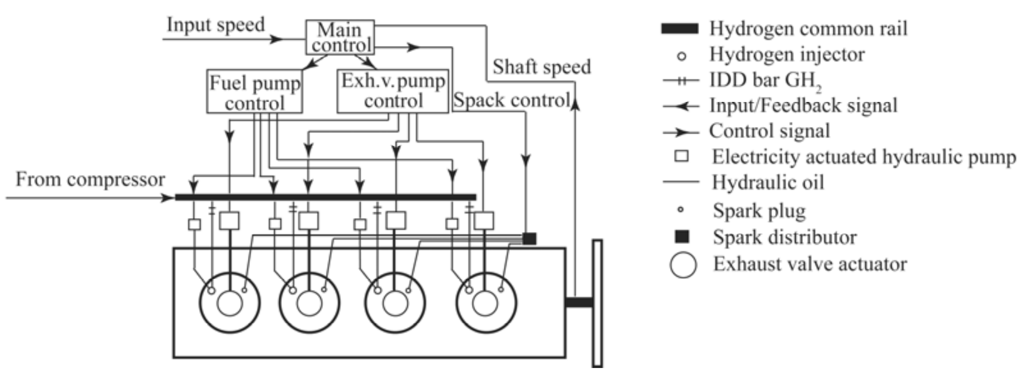

Fig. 7 Schematic Engine control systems

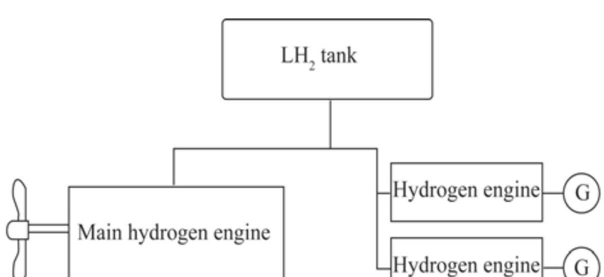

Fig. 8 Direct coupling propulsion

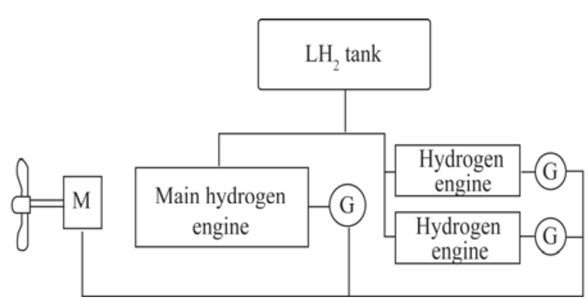

Fig. 9 Hydrogen electric propulsion

Many propulsion arrangements exist to propel the ship, one of them is to use the hydrogen internal combustion engine connected to the propeller via gearbox, and another one is a modern arrangement, by generating electricity by alternators to drive electric motors coupled to the propellers. Each arrangement has its advantages and disadvantages according to the field of usage. Figures 8 and 9 show these arrangements.

2.1.4 Gas turbine power plants

The gas turbine can be regarded as a natural development for the steam turbine, this is because both of them extracts work from a high energy flow; high pressure and temperature steam for the steam turbine and high pressure and temperature combustion gases for the gas turbine.

The concept of driving a turbine with hot gases was patented for the first time in 1791, the patent was granted for the Englishman John Barber, but the first design was the property of Dr. Franz Stolz in 1872. The first true gas turbine able to produce enough power than its needs for the compressor was built in 1903 by the Norwegian Agidius Elling, and in 1930 Sir Frank Whittle used the work of Agidius Elling to develop the principle of jet propulsion (Naval Forces, 2003).

The first vessel to be powered by gas turbine was the Royal Navy Motor Gun Boat MGB 509 converted in 1947 (Giampaolo, 2006). Since then the gas turbine was very successful in the naval field with thousands of gas turbines used for the propulsion of frigates, destroyers, corvettes, etc. The first gas turbine used for the commercial fleet was in 1949 onboard the oil tanker Auris, many designs for gas turbine powered commercial vessels didn't see the light due to the dramatic 1970's oil crisis, the gas turbines of this age were not able to run on lower and cheaper fuel grades.

Nowadays, the gas turbines found the success in two categories of commercial vessels, both relying on passengers; the fast ferries and the cruise liners. Since the year 2000, many vessels were powered by gas turbines, but most of them use the gas turbine in a combined configuration to achieve a more feasible and flexible propulsion solution due to the high fuel consumption of gas turbines, these combined configurations include the combined diesel and gas (CODAG) where the required power is produced by both diesel engines and gas turbines at the same time and at part load only one type of engines is operated according to the required power, the combined diesel or gas (CODOG) where the vessel is required at different power schemes and then only one type of engines is operated and this configuration is usual in navy vessels, the combined gas and steam (COGAS) where the exhaust of the gas turbine is used to provide enough heat for steam generation that is used in small steam cycle, and the recent combined diesel electric and gas (CODLAG) where diesel engines and gas turbines are used for electric power generation, part of this power is directed to the vessel electric consumers and the rest is used for electric propulsion motors.

There are two main types of gas turbines used in the marine field; the aero-derivative gas turbines and the industrial gas turbines. Both of them are mechanical drive gas turbines where a shaft rotates to drive a load, the other type of gas turbines is the jet gas turbines used in aircrafts.

The major disadvantage of gas turbines in the marine field is their low ability to work on heavy fuels since most of the marine gas turbines are of the aero-derivative types derived from aircraft industry. Only few gas turbines are available now with the ability to burn heavy fuels, those engines are derived from industrial heavy duty gas turbines working basically on heavy fuels in the land based applications. One of the most recent examples is the Siemens SGT-500 with the dual spool split shaft configuration.

For other marine gas turbines, the fuel used is either the marine gas oil (MGO) corresponding to ISO 8217 DMA grade or the JP5 jet fuel (Harrington, 1992).

The most used gas turbine in the marine field either commercial or military is the GE LM2500 with more than 800 engines in service in 1996. Marine gas turbines are available up to 50 MW but in discrete levels according to the available models. And they are provided in an acoustic enclosure with dimensions usually near the standard containers size. They are directly coupled to the propeller through gearboxes but in the recent configurations electric drives were chosen for the passenger ferries and cruise liners market. Astern motion is unavailable through the engine itself necessitating either a controllable pitch propeller or reversible gearbox and in the electric configurations the electric motor provides the astern motion (El-Gohary, 2012).

2.1.5 Hydrogen gas turbine

The basic design of hydrogen gas turbine follows the same simple steps as the ordinary gas turbines. It has been demonstrated in this paper that a marine gas turbine running on gaseous hydrogen can introduce a good alternative for ordinary marine power plants as no special technologies are needed and good performance can be achieved.

For this type of engines, the challenge is in the adoption of the new type of fuel for waterborne vehicles and also the difference between the properties of hydrogen and those of other types of fuels. One of these properties includes the combustion characteristics which are wide different than those of ordinary fuels. This may be overcome by using a mixture of hydrogen with other types of fuels like natural gas.

Table 1 compares the main characteristics of the above mentioned types of marine power plants; the steam turbines, diesel engines and gas turbines while Fig. 10 and Fig. 11 give a comparison between diesel engines and gas turbines for specific fuel consumption and weight respectively.

Table 1 Comparison for the main aspects of each type of power plants

Items	Steam turbines	Low speed diesel	Medium speed diesel	High speed diesel	Aero-derivative gas turbine
Power range /kW	Up to 60000	3000-100000	1000-25000	Up to 4000	Up to 50000
Applications	LNG and oil tankers	Most commercial vessels	Naval units and general cargo	Small units	Naval vessels and ferries
Cost	high	highest	Fairly high	Lowest in power range	Lowest at high power
Fuel	heavy	heavy	intermediate	light	light
SFC /(g • kWh^{-1})	260-360	160-180	165-210	200-250	210-400
Weight	Moderate	highest	moderate	low	lowest

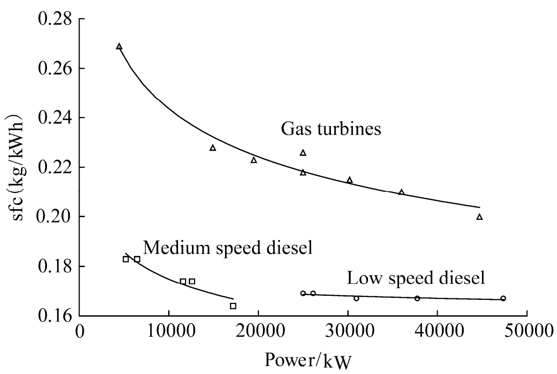

Fig. 10 Specific fuel consumption comparison of gas turbines and diesel engines

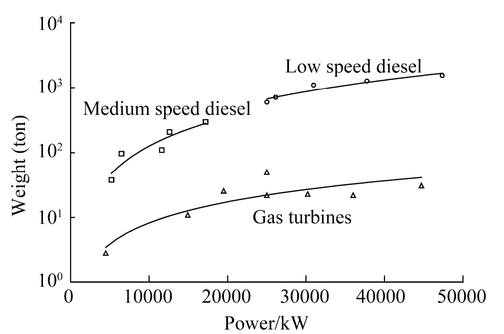

Fig. 11 Weight comparison of gas turbines and diesel engines

2.2 Overview of fuel cell technologies

2.2.1 History of fuel cells

It was in January 1839 that the first traces of fuel cells appeared when the German chemist Christian Friedrich Schönbein wrote an article in one of the scientific magazines of that time about his discovery; ozone and the reaction of hydrogen and oxygen. One month later, the Welsh scientist Sir William Robert Grove documented his observations based on Schönbein work and later introduced his first fuel cell model under the name of ‘gas voltaic battery (Woodyard, 2004).

It wasn’t until the twentieth century that the basic design of fuel cells was developed. The major development occurred between 1955 and 1958 leading to the Grubb-Niedrach fuel cell developed in General Electric. The first commercial use was in the 60’s NASA Gemini space program. Another key development was the introduction of a 5 kW stationary fuel cell by the British engineer Francis Thomas Bacon in 1959, his design was licensed a year later for the US space program.

Currently, more and more fuel cell manufacturers enter the market each day; the list includes Ballard, Hydrogenics and Siemens from Germany, United technologies from Belgium and Plug Power from the USA.

2.2.2 Types and applications

All fuel cells share a common structure of anode, cathode and an electrolyte in between. The main difference between different types lies in the type of materials used for the device components.

Only five types are the dominant types and the others are variations of the main five. The five types are: Proton Exchange Membrane Fuel Cell (PEMFC), Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC) and Solid Oxide Fuel Cell (SOFC).

As a definition, the fuel cell is an electrochemical device that converts the chemical energy in the fuel to electric energy. The difference between fuel cells and ordinary batteries is that fuel cells can run almost forever if the supply of fuel is not interrupted. The basic fuel of fuel cells is the hydrogen gas reacting with the atmospheric oxygen producing electricity, water and heat as a reverse operation for the water electrolysis.

The fuel is not necessarily gaseous hydrogen; compounds including hydrogen may be used like hydrocarbons and alcohols.

Figure 12 shows the essential components of fuel cells; the anode where the fuel enters the system, the electrolyte responsible for the passage of ions between the two electrodes and the cathode where the oxidant enters the system.

The main application for fuel cells according to their nature as electrochemical device is the electric generation. This application is used everywhere; in stationary as well as mobile applications in land vehicles, marine vehicles or even spacecrafts. But not all types of fuel cells can be used in all applications; some are more suitable for a specific

application than the others.

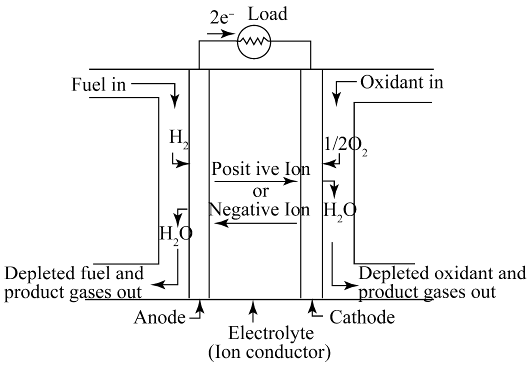

Fig. 12 Schematic of an individual fuel cell

For the marine field, fuel cells are intended to provide the power for propulsion in small units or auxiliary power for large units. Many development projects are in place currently; one of them is the Hydrogen Hybrid Harbor Tug in The Netherlands which will be operated by fuel cells for the standby and mobilization power levels and by diesel engines for the pulling/pushing operations.

DetNorskVeritas, MTU, Wärtsilä and others are the members for a project called Fellowship to develop fuel cells intended solely for the marine use. Other classification societies are working on issuing general guidelines for the use of fuel cells onboard ships. Another project called Zemship (Zero emissions ship) is conducted by Germanischer Lloyd, Linde–Group and Proton motor to develop a fuel cell powered passenger ship.

Fuel cells, however, are not new to the marine sector, navies around the world used fuel cells for the quiet supply of power for submarines for years. Siemens in Germany provided fuel cell units for submarines as well as small auxiliary power units for naval vessels. One of the successful examples is the type 212 German submarines. Table 2-2 gives a comparison between the main characteristics of the different types of fuel cells.

Table 2 – Comparison of fuel cell types

Fuel cell type	Electrolyte	Temperature range /°C	Output /kW	Efficiency /%	Applications
PEMFC	Solid organic polymer	50-100	<1-250	25-58	Backup power Small distributed generation Transportation
AFC	Aqueous solution of potassium hydroxide	90-100	10-100	60	Military Space
PAFC	Liquid phosphoric acid	150-200	50-1000	>40	Distributed generation
MCFC	Liquid solution of lithium, sodium and/or potassium carbonates	600-700	<1-1000	45-47	Large distributed generation
SOFC	Yttria stabilized zirconia	600-1000	<1-3000	35-43	Auxiliary power Large distributed generation

3 Conclusions

The use of steam turbines once favored is no longer favored for newly built due to the system complexity and low efficiency. Even the LNG sector is searching for new propulsion schemes to be installed to eliminate the need for the old fashioned power plants. This leaves the competition playground wide-open to the diesel and gas turbines. Nobody can precisely decide which method is the best however, the gas turbines have more advantages, but the diesel engine is more reliable, and has good maintainability characteristics. The world is full of technicians able to work with diesel engines, and its efficiency is higher than gas turbines.

Marine turbines use marine diesel oil as fuel, and in order to move a step closer to the future, new fuel resources must be chosen in efforts for the fueling of marine turbines to have a clean and efficient shipping industry. The natural gas and the hydrogen resources are the two candidates for this operation; the natural gas for the short term development and the hydrogen for the long term development. It has been recommended to assess the performance of the turbine under these two cases.

Apart from all technical advantages the gas turbines have over the diesel engines, another key difference exists which is the emission levels, the gas turbines have lower emission levels than diesel engines making them more friendly to the environment. The fuel cells remain the best when the environment is considered but they are not ready enough to compete as a main propulsion prime mover yet.

Fuel cells are intended to provide the power for propulsion in small units or auxiliary power for large units for the marine field which uses hydrogen and natural gas as a fuel.

4 Recommendations

The recommendations for a better future of the marine power plants can be concluded in the following points:

1) Increase the interest of ship owners and designers in the gas turbine market especially for the small and medium sized vessels where high shaft speeds will not require large

reduction ratios.

2) Promote the use of natural gas in the marine transportation sector to have a better environment until the hydrogen is ready to be used on a large scale.
3) New research programs are needed to find efficient solutions for the problems associated with the application of hydrogen in marine power plants, either in internal combustion engines or in fuel cells.

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